

element14 Essentials: Connectors II

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Connectors II

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1. Introduction

While consumer and industrial-grade connectors have essentially identical functions, industrial connectors are utilized in applications that diverge considerably from those used in consumer electronics equipment. What differentiates industrial connectors from PCB and common I/O connectors is the substantial amount of engineering that went into designing the integral environmental protection needed for proper connector operation in many harsh or hazardous industrial environments. If you are an electronics student, a hobbyist in the maker community, or if you have been a design engineer focused on consumer electronics products, this learning module will expand your knowledge of the most common types of industrial connectors used in a wide range of applications, spanning IoT, M2M communications, motor control, parameter monitoring, energy production, and more.

2. Objective

The objective of this learning module is to provide you with the essentials of industrial connectors. You will first review the purpose and functions of common types of home and commercial connectors in order to appreciate the differences between these connectors and industrial connectors. In the later sections, you will gain a thorough understanding of the types, features, and applications of industrial connectors.

Upon completion of this learning module, you will be able to:

- Discuss the four types of home and commercial power connectors.
- Identify the difference between an IEC and a NEMA connector.
- Understand the main differences between a consumer and an industrial connector.
- Determine the level of ingress protection of an industrial connector based upon the EN/IEC 60529 IP rating system.
- Discuss the different types of industrial connectors and their applications.

3. Review

Before discussing the types of industrial connectors, let's begin this learning module with a brief review of connector basics, starting with the definition of a connector. A connector was defined in the [element14 Connectors Essentials One](#) learning module in the following way:

Definition: *A connector is a device that is capable of connecting two circuit points, signals, or sub-systems with electrical integrity, mechanical durability, environmental protection and safety.*

- **Electrical Integrity** - when connectors mate two points of a circuit with a very low contact resistance and provide protection from electromagnetic interference (EMI) and/or electrostatic discharge (ESD).
- **Mechanical Durability** - when a connector can withstand vibrations or environmental abuse without causing a failure in electrical integrity.
- **Environmental Protection** - when a connector's design meets the IP (Ingress Protection) ratings defined in the international standard EN/IEC 60529 for preventing the ingress of water, dust, debris, and other contaminants that would otherwise interfere with the electrical integrity of the connection.
- **Safety** - when a connector is designed with features that eliminate personnel hazards, or the risk of fire, shock or electrocution.

While this extended definition was originally written for a discussion on PCB-level, I/O peripheral and consumer product connectors, it also applies to the broad category of industrial connectors. But the key difference between consumer and industrial connectors is the degree by which each of these features is emphasized in the design of the connector.

To fully appreciate the engineering that went into the design of industrial connectors, it is worthwhile to digress a moment and discuss briefly some common types of home and commercial connectors. Understanding the differences between home/commercial and industrial connectors is a good way to become familiar with the unique characteristics of industrial connectors.

4. Common Types of Home and Commercial Connectors

Power connectors are commonly used on extension cords and AC/DC adapters to power computers, home appliances and any number of devices we use in our daily lives. But a connector used to connect power to a typical kitchen appliance (e.g., toaster, coffee pot or blender) is quite different than one that would be used to power a 10 HP A.C. induction motor supplied by a 3-phase Wye (208/120V) power distribution system for an HVAC application. In general, power connectors, used in homes or commercial buildings, are grouped into the following types based upon their contact configurations:

- Straight Blade
- Locking
- Pin & Sleeve
- Poly-Phase

Straight Blade: The straight-blade type is used to supply light-duty, general-purpose, electrical devices. The blades are flat, conductive and permanent contacts that mate with corresponding blade-sockets in the receptacle/inlet.

Locking: The locking type is used to supply moderate-to-heavy duty, commercial equipment that do not require a sealed connector. This type features a curved ground pin and an integral locking mechanism. An operator needs to insert-and-twist the connector/plug in the receptacle/inlet to supply power to the load and lock the plug into place. This locking feature provides increased protection against accidental disconnection. Connection security is an important feature because if a connector were removed from its receptacle while it was connected to a load, an arc flash event is likely to occur, resulting in a possibly deadly personnel safety hazard.

Pin-and-Sleeve: The pin-and-sleeve type is a heavy duty power connector that's constructed with a large contact pin that mates with a surrounding contact sleeve when connected. These connectors are employed where higher voltages and currents are utilized.

Poly-Phase: The poly-phase type is a heavy-duty commercial power connector that connects a 3-phase power distribution system to a 3-phase load such as a motor or a heater.

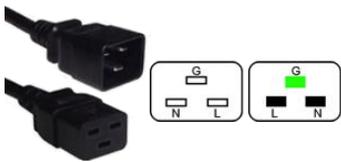
- 4.1 IEC Power Connectors

In order to ensure that a power connector will mate to equipment manufactured in different parts of the world, the design of connectors has been “harmonized” via manufacturing standards that are developed by organizations such as the International Electrotechnical Commission (<http://www.iec.ch>).

The International Electrotechnical Commission (IEC) is a non-profit, non-governmental, international standards organization that publishes standards for electrical, electronic and other technologies. The relevant IEC standard for the connectors discussed in this learning module is the [IEC 60320](#):Appliance couplers for household and similar general purposes. The IEC 60320 sets the guidelines for two-pole appliance couplers with and without an earth ground pin for powering household and similar devices to a mains supply that does not exceed 250 VAC /16A. There are 13 pairs of IEC connector types. Here are a few examples:



IEC C5/C6 connectors are a very common type of personal/home power connector. They are rated for 250V/2.5A and include an earth (safety) ground wire. They are commonly called a clover leaf or a Mickey Mouse (after the Disney cartoon character) connector due to their cross-sectional shape. C5/C6 connectors are commonly used on laptop power supplies.



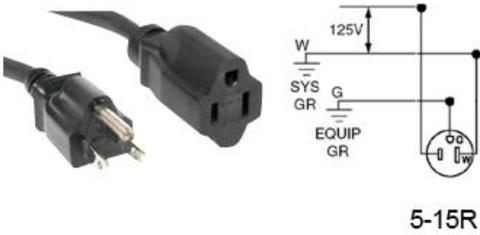
While the IEC C5/C6 connector is used for personal or home applications, the **IEC 19/20 connector** is used for commercial purposes such as datacenter enterprise-class servers or rack-mounted power distribution units (PDUs). It is rated for 250V/16A. It has a hot line (L), neutral (N) and earth safety ground (G) pins. As you can see from the image, its contacts are arranged in a unique configuration to ensure the plug/connector can only be mated to the proper receptacle/socket.



- 4.2 NEMA Power Connectors

Another common home and commercial connector is the NEMA connector. The National Electrical Manufacturers Association (www.nema.org) is the U.S. association of electrical equipment and medical imaging manufacturers that develops NEMA standards for the manufacturing of home or commercial power connectors. NEMA connectors are primarily used in North America; however, they can be used in other countries. They have a broader range of voltage and current ratings than IEC connectors, 125 to 600 V and 15 to 60 A, respectively.

The relevant NEMA standard for the connectors discussed in this learning module is [ANSI C119.6-2011](#): The American National Standard for Electric Connectors-Non-Sealed, Multipoint Connector Systems Rated 600 V or Less for Aluminum and Copper Conductors. The standard covers non-sealed, multipoint distribution connectors rated 600 V or less used to make electrical connections between aluminum-to-aluminum, aluminum-to-copper or copper-to-copper conductors for above-grade electric utility applications. There are 13 main categories of NEMA connectors (i.e., NEMA 1, 2, 5, 6, 7, 10, 11, 14, 15, 18, 21, 22, 23), covering both locking and non-locking types. Here are a few examples:



NEMA 5-15 connectors are one of the most common household power connectors employed in the U.S. They are rated at 125V/15A. They are a straight-blade type and include an earth (safety) ground pin. They are used to power TV sets, radios, computers and all types of small home appliances such as a blenders, toasters or coffee pots.



In situations where there is a need for improved connection security – so the connector cannot be pulled out of its outlet in an energized state – the **NEMA L5-15** is utilized instead of the NEMA 5-15. This variant of the NEMA 5-15 has a curved ground contact pin that will lock the plug/connector into the receptacle/socket after it is inserted and twisted. But it is worthwhile to note that since this connector is a non-sealed type, the connector should not be used in wet, harsh or similar environments.



One of the advantages of NEMA connectors is the wide variety of power distribution systems for which it can provide a separable power connection. For example, a NEMA L14-30 connector is capable of connecting loads to two-pole, four-wire, 240/120 VAC power systems up to 30A. This type of multi-voltage connector simplifies installation by reducing the need and cost of hard-wiring multiple connections, while the locking feature aids in connection security.

5. Introduction to Industrial Connectors

The previous section was a short overview of common home and commercial connectors. Both IEC and NEMA connectors have a wide range of sizes in order to provide an effective connection solution for different power systems and voltage/current ranges. Moreover, they are employed in home and office applications around the world, which is a testament to their quality, reliability, and safety. **But are they a good fit for the industrial environment?** To answer the question, let's compare a NEMA and an industrial connector with similar ratings.

Non-Sealed Connectors



NEMA L16-30: 480V/30A, Non-Sealed (IP20)

Splashproof Industrial Connectors



Amphenol® Industrial Amphe-309 Series: 380-450V / 32A Splashproof (IP44)

Both of these connectors have similar ratings and would be used in similar applications such as connecting 3-phase loads to a 3-phase, 4-wire (L-L-L-G) power distribution system. But they are different in several respects, such as:

Connector Pin Exposure: The NEMA L16-30 has exposed contact pins while the Amphe-309 industrial connector's pins are shrouded by a casing to provide a greater amount of personnel hazard protection.



Color Coding: The Amphe-309 industrial connector's casing is color coded according to voltage and amperage ratings. In industrial situations where there are a lot of connectors mounted to a junction box (See image on left), the color coding of connectors is a decided advantage as far as operational readiness and maintenance convenience goes.

Ingress Protection: When the NEMA L16-30 plug is mated to its receptacle it provides a highly conductive and secure electrical connection. Despite these benefits, it has only an IP20 rating, which indicates it is non-sealed and therefore not recommended for use in wet/washdown industrial environments. Conversely, the Amphe-309 Series industrial connector has an IP44 rating, indicating that it is sealed to the point of making it splashproof.

Keep these three differences in features in mind as we discuss the different types of industrial connectors in the subsequent sections of this learning module.

6. Ingress Protection Rating System

In the last section, we touched on the topic of ingress protection. Let's take a closer look at this concept in this section. Environmental protection is a key feature of industrial connectors. As we learned in the last section, a non-sealed connector is not recommended for use in wet industrial environments. But how can we tell if a specific connector has the right level of environmental protection for a particular industrial environment?

This is done with an ingress protection (IP) rating system.

The EN/IEC 60529 standard has delineated an IP rating system that indicates the level of protection provided by an enclosure. While the standard explicitly defines these as IP codes for electrical enclosures, connector manufacturers also use this standard to identify the level of ingress protection for their products. The ingress protection rating system consists of “IP” plus a two digit code. The rating system is described in the following table:

IP First Number – Protection Against Ingress of Solids	Second Number – Protection Against Ingress of Liquids
0 – No special protection	0 – No protection
1 – Protected against solid objects over 50 mm, e.g. accidental touch by person's hands	1 – Protection against vertically falling drops of water e.g. condensation
2 – Protected against solid objects over 12 mm, e.g. persons fingers	2 – Protection against direct sprays of water up to 15° from the vertical
3 – Protected against solid objects over 2.5 mm (tools and wires)	3 – Protected against direct sprays of water up to 60° from the vertical
4 – Protected against solid objects over 1 mm (tools, wires, and small wires)	4 – Protection against water sprayed from all directions - limited ingress permitted
5 – Protected against dust limited ingress (no harmful deposit)	5 – Protected against low pressure jets of water from all directions - limited ingress
6 – Totally dust tight	6 – Protected against temporary flooding of water, e.g. for use on ship decks - limited ingress permitted
N/A	7 – Protected against the effect of immersion between 15 cm and 1 m
N/A	8 – Protects against long periods of immersion under pressure
N/A	9k – Protected against close-range high pressure, high temperature spray downs.

Example: What does IP67 mean?

Answer: A connector that is totally dust tight (6 – first number) and water resistant (7- second number - protected against the effect of immersion between 15 cm to 1m).

7. Types of Industrial Connectors

Industrial power connectors are designed to safely and reliably provide power to equipment in harsh, high temperature, and other extreme environments such as wastewater treatment plants, oil production facilities (offshore rigs), mining operations, food/pharmaceutical processing plants and others. In general, industrial connectors are grouped in the following categories:

- Harsh Environment
- High Vibration
- Explosion Proof
- Multipin
- Vehicular
- Solar

- 7.1 Harsh Environments



Certain types of industrial connectors are specifically built for use in harsh environments. So, let's examine what is meant by the term "harsh environment" in this context. Generally speaking, a harsh environment is one that places physical stresses on a piece of equipment. These stresses can include very high or low temperatures, high pressures, high vibrations, or explosion hazards. Harsh environment connectors are designed for durability and are environmentally sealed to offer a high degree of ingress protection. The range of applications for harsh environment connectors is rather wide, but they typically include Aerospace, Geophysical, Heavy Equipment, Rail & Mass Transit, Process Control, Factory Automation, Construction, and Agriculture.



Amphenol® Industrial Star-Line™ Power/Signal Connector

Amphenol® Industrial Star-Line™ Series connectors are a good example of a harsh environment connector. They are heavy duty, environmentally sealed connectors that are rated for a temperature range from -67°F to +225°F, a voltage range up to 1,000 VAC/DC, and come with an IP68 rating. They are constructed with machined aluminum and have a hardcoat plating that's corrosion resistant for up to 300 days of salt spray. These connectors are commonly used in petrochemical, geophysical, complex ground support cable networks, process control systems and instrumentation systems.



Amphenol® Industrial AT Series Thermoplastic Circular Connectors

Industrial environments, such as agriculture, construction or trucking, are subject to the ingress of moisture, dust, debris and other contaminants that can impact the electrical integrity of a connection. In these applications, an environmentally sealed connector is a must. The Amphenol® Industrial AT Series Thermoplastic Circular Connectors is an example of an industrial vehicle diagnostic system connector that's designed for harsh environments. The round receptacles include strain relief for the wires coming out of the back of each unit and a wave spring for higher vibration applications. It has a positive reverse bayonet retention system for quick mating. It meets the requirements of SAE J1939, the standard for communication and diagnostics among industrial vehicle components.



Amphenol® Industrial ACA-B Series, MIL-DTL-5015 Series Equivalent

For heavy duty power and signal applications in factory automation, robotics and process control equipment Amphenol® Industrial ACA-B Series connectors provide an environmentally sealed, quick-connect, positive-mating, customizable, bayonet-style connector. The shell is made from aluminum alloy with zinc alloy plating. Its contacts are machined from copper alloy or brass and can be plated with gold or silver. It has an IP67 rating. The insulators are made of high quality polychloroprene material and can withstand temperatures from -55°C to +125°C. Similar in design to a MIL-DTL-5015 connector, the ACA-B series has proven itself valuable in the military ground vehicle and alternative energy markets as well.



Amphenol® Industrial Max-M12 Series, Datalink Connectors

In the past, high speed data transmission lines have been installed into industrial applications with little regard to high vibration, high temperature or harsh environments. But as more heavy equipment, rail transit, and process control systems utilize high speed datalinks, the need for a ruggedized connection system has increased. The Amphenol® Industrial Max-M12 Series data communication connector is built to withstand harsh environments and electrical noise. Based on IEC 61076-2-101 and SAE J 2839 standards, the Max-M12 Series can withstand connector-to-cable retention forces of 444 newtons (N) and contact retention forces of 110 N (tested at 100 mating cycles minimum). All versions of this high speed connector are IP67 or above, making them dust and waterproof, and resistant to high pressure and high temperature washdowns. It's rated for 60-250 VAC/DC, depending on the model, and 4A.

7.2 High Vibration Connectors



Most heavy and industrial equipment – diesel engines, power generators, air compressors,

and excavators –produce vibrations. Destructive torsional and harmonic vibrations can impact the reliability of a connector. But even normal vibrations can cause fretting corrosion in a connector – mechanical wear of electrical contact surfaces due to vibrations. In either case, the recommended solution is to employ high vibration industrial connectors that are designed to perform reliably in this type of industrial environment.



Amphenol® Industrial AHVB Series, High Vibration Connector Kit

To maintain the electrical connection in a high vibration environment, Amphenol® Industrial AHVB Series connectors employ high vibration brush terminals designed to withstand harsh environments with zero fretting. By intermeshing two small wire bundles together, a superior electrical connection is made with 14 to 70 points of contact per mated pair. The brush-like terminal technology is comprised of multiple strands of high tensile strength wire bundled together on each side of the contact and hooded for protection (see below).



Amphenol's high vibration brush (AHVB) terminal is designed to withstand vibrations of at least 53.8 G(rms) at 8 hours per axis and 2,000 Hz. It is ideal for on-engine applications and fixed positions for all signal applications, including in-lines, sensors, fuel systems, and control modules where high vibration fret resistance and environmental performance is critical to function.



Amphenol® Industrial Tru-Loc Series Connector

Another type of high vibration connector is the Amphenol® Industrial Tru-Loc Series connector. It's designed for placement under valve covers on diesel engines, in high vibration sensors or on other devices such as fuel injectors, splitters, or pass-through connections. It features a molded thermoplastic main plug body with secondary latch and silicone rubber wire seals to support an IP67 rating. It has a fluoroelastomer main joint seal that's resistant to many fluids, including diesel fuel. They are rated for high vibrations at 32G(rms). It includes 2-way, 4-way, and 6-way inline plugs and receptacles. It has an operating temperature range of -40°C to +125°C or +150°C, depending on the model purchased.

- 7.3 Explosion Proof Connectors



Some industrial environments are explosion hazards due to the presence of flammable gases, dusts, mists or vapors in their atmospheres. Petrochemical refineries, land and offshore drilling systems are environments that can have flammable atmospheres. But flour & feed mills, grain silos & elevators, and coal & coke plants are dust explosion hazards. To mitigate the risks associated with these hazardous environments, explosion proof connectors have been designed to ensure that the device itself does not ignite an explosive chain reaction. In the context of industrial environments, explosion-proof connectors are manufactured with greater precision so that the arcing or sparks that occur inside the device do not ignite flammable gases, vapors or mists as well as combustible dusts that are present in the surrounding atmosphere.



Amphenol® Industrial Amphe-EX Series, Hazardous Location Connectors

Amphenol® Industrial AMPHE-EX Connectors are designed to provide signal, power, RF, fiber optic or Ethernet connections in potentially explosive environments and such as [ATEX](#) and [IECex](#) Zone 1 rated areas. Featuring a smaller interface than most heavy duty hazardous rated connectors, AMPHE-EX connectors are IP68 rated and made from high tensile strength aluminum and plated with a hard anodic coating as per [Mil-A-8625](#) so they can withstand the most extreme environments. Bar stock components are precision machined with points of impact designed for extra strength. Double-lead acme threads allow for a self-cleaning mating action. AMPHE-EX connectors offer a complete array of insert patterns, ranging from 2-No.20 contacts through 79-No. 22D contacts as well as ATEX- and IECex-approved USB and RJ45 connections.

- 7.4 Multipin Connectors



Factory automation and industrial control systems utilize multipin connectors as part of the interconnection system for the programmable logic controllers (PLCs), sensors, gateways, AC/DC drives, and other equipment that control, monitor, or actuate a manufacturing process. Industrial environments that are prone to corrosion or moisture require industrial-grade, multipin connectors with sealing to provide a higher level of protection than required for general duty, non-environmental, benign environments.



Amphenol® Industrial P-Lok® Series

Amphenol® Industrial P-Lok® Series are environmentally sealed, multipin connectors that provide power, signal or hybrid electrical connections for a wide variety of industrial applications, including motion control & vision systems, industrial controls and communications. For complete environmental sealing, they feature an o-ring seal at the rear of the coupling ring and a corresponding o-ring seal on the receptacle to seal the front of the coupling ring. A tapered compression grommet creates a complete seal around the cable jacket.

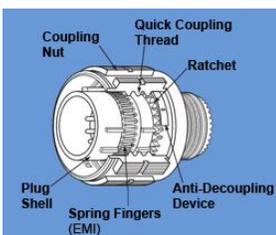


Featuring an IP67 rating, P-Lok connectors are manufactured from machined aluminum and finished in black hard coat, providing a strong industrial-grade connector. It has a rapid mating/coupling system that creates a positive locking action of the plug and receptacle through the use of a spring loaded coupling ring on the plug and stainless steel ball bearings on the receptacle. This system is similar to the coupling system that is employed on pneumatic hose connections, but with an added audible and tactile confirmation of a positive locking connection. P-lok connectors eliminate all the issues that are inherent with Mil-C-5015 threaded connectors such as cross threading, improper mating and loose connections. It has service ratings from 250 VDC to 1750 VDC and up to 500 amps.



Amphenol® Industrial Amphe-Lite™ Series, Circular Connector, MIL-DTL-38999 Series III Equivalent

The Amphenol® Industrial Amphe-Lite™ Series connectors are designed for communications equipment manufacturers with signal, power, RF or fiber optic interconnect requirements in harsh environments such as communication towers, outdoor and roof-top applications. This 38999 Series III composite connector series is ideal for communications equipment, manufacturing process control and medical equipment. They offer very high performance in harsh environments, while being cost effective enough for general duty and non-environmental applications.



A positive shoulder to shoulder coupling design, grounding fingers, and electroless nickel plating provide

superior EMI shielding capability (65 dB minimum at 10 GHz). Amphe-Lite connectors can be used with many contact types: fiber optics, shielded coaxial, twinax ground plane versions, and power contacts. A non-magnetic Amphe-Lite with an unplated, non-conductive shell is also available.

- 7.5 Vehicular Connectors



Renewable energy is an important area of power and environmental engineering today. As a result of the needs for cleaner and more-efficient energy sources, electric vehicles (EVs) and plug-in hybrids (HEVs) have gained market traction, resulting in a projected global growth from 2.6 million in 2015 to over 6 million by 2024. In response, this projected growth has spawned the development of new vehicular, charging plugs that barely existed a decade ago.



Amphenol® Industrial Universal Power Connector for Hybrid Electric Vehicles

The Amphenol® Industrial Universal Power Connector (UPC) is a plastic, power connector specifically designed for use as an interconnect for the EV and Hybrid markets. The 2-pole and 3-pole connectors incorporate patented RADSOK® technology for higher amperage, lower T-rise & voltage drop, and less contact resistance. RADSOK's twisted grid configuration allows for up to 50% more current to pass through the same size pin, while also providing increased reliability, cycle durability (500 mating cycles minimum), and lower mating forces. It has a touch proof rating as per UL2251 and an IP 67 / IP69k rating when mated. The plastic shell structure is lightweight with a small footprint and a rated continuous power up to 400 A. It has an EMI rating of 60dB/100M and meets the requirements for UL 94V-0, the plastics flammability standard released by Underwriters Laboratories.

- 7.6 Solar Connectors



Solar energy is one of the most common types of renewable energy today. Consider this: Nearly 784,000 U.S. homes and

businesses have solar systems. There are now over 22,700 MW of cumulative solar electric capacity operating in the U.S., enough to power more than 4.6 million average American homes, according to the Solar Energy Industries Association® (www.seia.org). Solar energy has found a commercial market as well with utility-scale solar power facilities in operation for over two decades. In response to the growth in solar power, a new range of power connectors have been developed for the solar industry.



Amphenol® Industrial Solar Plug and Socket Connector

The Amphenol® Industrial Solar Technologies H4 PV is a solar connector that can be used by solar panel manufacturers, installers and OEMs for both thin film and crystalline silicon technologies. It is fully intermatable with the industry standard connector and meets the US National Electrical Code (NEC) 2008/2011 standard “as is” with no additional locking-clip required. It is rated for 1500V (IEC/TUV) or 1000V (UL) and a maximum current between 32 to 65A, depending on the size. It is IP68 rated with a UL94-V0 flammability rating. It can operate from -40°C to +85°C.

*Trademark. Amphenol® Industrial is a trademark Amphenol Corporation. Other logos, product and/or company names may be trademarks of their respective owners.

Test Your Knowledge



Are you ready to demonstrate your Connectors knowledge? Then take a quick 15-question multiple choice quiz to see how much you've learned from this Essentials Connectors 2 module. [Take Quiz](#)